Large Unmanned Aircraft System Operations in the National Airspace System – the NASA 2007 Western States Fire Missions

Gregory P. Buoni [*] and Kathleen M. Howell [†]
NASA Dryden Flight Research Center, Edwards, California, 93523

The National Aeronautics and Space Administration (NASA) Dryden Flight Research Center (DFRC) Ikhana (ee-kah-nah) project executed the 2007 Western States Fire Missions over several of the western United States using an MQ-9 unmanned aircraft system (UAS) in partnership with the NASA Ames Research Center, the United States Forest Service, and the National Interagency Fire Center. The missions were intended to supply infrared imagery of wildfires to firefighters on the ground within 10 minutes of data acquisition. For each of the eight missions, the NASA DFRC notified the Federal Aviation Administration (FAA) of specific flight plans within three or fewer days of the flight. The FAA Certificate of Waiver or Authorization (commonly referred to as a "COA") process was used to obtain access to the United States National Airspace System. Significant time and resources were necessary to develop the COA application, perform mission planning, and define and approve emergency landing sites. Unique aspects of flying unmanned aircraft created challenges to mission operations. Close coordination with FAA headquarters and air traffic control resulted in safe and successful missions that assisted firefighters by providing near-real-time imagery of selected wildfires.

Nomenclature

AFB	=	Air Force Base
AMS	=	Autonomous Modular Sensor
ARTCC	=	air route traffic control center
ATC	=	air traffic control
ATCAA	=	ATC assigned airspace
BAER	=	Burn Area Emergency Rehabilitation
COA	=	Certificate of Waiver or Authorization
DFRC	=	Dryden Flight Research Center
ELS	=	emergency landing site
FAA	=	Federal Aviation Administration
GCS	=	ground control station
GPS	=	global positioning system
IR	=	infrared
NAS	=	National Airspace System (United States)
NASA	=	National Aeronautics and Space Administration
NIFC	=	National Interagency Fire Center
RSO	=	Range Safety Office
RVSM	=	Reduced Vertical Separation Minimum
UAS	=	unmanned aircraft system
USFS	=	United States Forest Service
WSFM	=	Western States Fire Missions
3-D	=	three-dimensional

[*] Operations Engineer, Operations Engineering, P.O. Box 273 / Mail Stop 1806, Edwards, California 93523.
[†] Operations Engineer, Operations Engineering, P.O. Box 273 / Mail Stop 1806, Edwards, California 93523.

I. Introduction

THE goal of US civilian unmanned aircraft system (UAS) operators and the Federal Aviation Administration (FAA) (Washington, District of Columbia) UAS Program Office is to safely operate unmanned aircraft in the United States National Airspace System (NAS) using the "file-and-fly" capability that is the current norm for manned aircraft. "File-and-fly" implies two capabilities for aircraft operation: the aircraft could fly anywhere in the NAS; and FAA flight clearance can be requested and obtained within 1 hr prior to the proposed flight. Some commercial, scientific, and government UAS operators could take advantage of this capability if it were available today. Although "file-and-fly" is not yet a reality for UAS operations, the National Aeronautics and Space Administration (NASA) Dryden Flight Research Center (DFRC) (Edwards, California) was able to fly their Ikhana unmanned aircraft over eight of the western United States. These flights took place between August and October 2007 in support of firefighting operations. The flight plans were submitted to the FAA between 24 and 72 hr prior to each flight. The Ikhana aircraft is an MQ-9 (General Atomics Aeronautical Systems, Incorporated, San Diego, California) UAS that has been modified for civilian use. "Ikhana" is a Choctaw word meaning "conscious" or "aware." Figure 1 shows the Ikhana aircraft flying during a Western States Fire Mission.

II. The NASA Western States Fire Missions

The NASA Western States Fire Missions (WSFM) was the culmination of the Wildfire Research and Applications Partnership led by the NASA Ames Research Center (ARC) (Moffett Field, California). This project began in 2003 and was a partnership with the United States Forest Service (USFS) and the National Interagency Fire Center (NIFC). The intent of this effort was to demonstrate a system that captures infrared (IR) data from wildfires, and presents it in near-real-time to firefighters on the ground during the western United States (US) wildfire season (August through October). A goal was to capture data over wildfires in any of the 11 western states: California, Oregon, Washington, Nevada, New Mexico, Arizona, Idaho, Montana, Utah, Wyoming, and Colorado. The NIFC generally monitors between dozens and hundreds of active wildfires at any one time, thus, there is a desire for the aircraft to gather data from 10 to 15 wildfires during any particular mission with satellite data correlation when possible. Additionally, there was a research desire to monitor a single wildfire for several hours at a time. Post-burn information is also valuable to the NIFC and the USFS to determine what types of rehabilitation activities might be required in previously burned areas.

The NASA DFRC Ikhana project team integrated the NASA Ames Autonomous Modular Sensor (AMS) payload into the Ikhana system, obtained FAA flight clearance, and operated the aircraft over active wildfires in the western United States. Integration activities included establishing the ground infrastructure necessary to transmit the downlinked data from the ground control station (GCS) at NASA Dryden to NASA Ames for appropriate dissemination.

III. History and Previous Work

An attempt was made to fly the WSFM in 2006. Using a NASA DFRC contract with General Atomics Aeronautical Systems, Incorporated (GA-ASI), the Altair® UAS was to perform the WSFM. In this relationship, GA-ASI was responsible for building the pod to house the AMS sensor package and for integrating that pod and payload onto the aircraft. The NASA DFRC team was responsible for planning the flights and obtaining the FAA Certificate of Waiver or Authorization (commonly referred to as a "COA") to overfly the wildfire incident areas. The NASA DFRC team began working with the FAA regarding the COA in early 2006.

Although significant progress was made in creating a complete COA application through coordination and negotiation with the newly-created FAA Headquarters Unmanned Aircraft Systems (UAS) Program Office, by September it became clear that COA approval could not be achieved until after the 2006 wildfire season had ended. The project elected to pursue an alternative approach that would allow a "Fire Mission" to occur in airspace immediately adjacent to the R-2508/R-2515 restricted airspace that the NASA DFRC normally uses. The COA for this more limited operating area was issued on October 19, 2006 and was valid through December 1, 2006. Using this authorization, a 21+ hr flight was performed from October 24, 2006 to October 25, 2006 over a controlled-burn area of Yosemite National Park. The data confirmed that a satellite wildfire detect was indeed accurate, and a second wildfire was observed with the AMS payload.

After the Yosemite flight, as this flight became known, the project stood down and began working on plans for the 2007 wildfire season; however, the wildfire season in Southern California was not yet over. During the early morning hours of October 26, 2006, a wildfire that would eventually be known as the Esperanza wildfire erupted near Cabazon, California. That wildfire would eventually grow to over 40,000 acres, destroy 34 houses, and kill five firefighters. The NASA DFRC made a request to the FAA on Friday, October 27, 2006 for an emergency COA

extension to the Yosemite COA that would allow a WSFM flight over the Esperanza wildfire. The FAA used a newly-created process to issue the COA extension that evening. One day later, on the evening of Saturday, October 28, 2006, the Altair® aircraft took off on a 16+ hr mission and obtained IR data that was passed to fire commanders and firefighters on the ground. This mission also included the capture of Burn Area Emergency Rehabilitation (BAER) post-burn data that NASA Ames and the NIFC also desired.

IV. The 2007 Mission Plan and Certificate of Waiver or Authorization Application

The 2007 WSFM COA application was built from the previous year's experience and application. All the details of the 2007 mission plans and pertinent Ikhana UAS information were submitted to the FAA Headquarters UAS Program Office online using the new electronic means instituted for applying for a UAS COA.

A. Certificate of Waiver or Authorization Application Philosophy

The NASA DFRC Ikhana project decided to change the 2006 WSFM plans as little as possible and submit an updated plan for the 2007 WSFM because the Ikhana project understood that the FAA considered the 2006 COA application to be almost complete. The COA challenge for 2007 was to collect all of the 2006 information, reformat that information into the FAA UAS COA Online System structure, and communicate that information effectively. The Ikhana project also decided to submit as complete an application package as possible. This decision eventually entailed the creation of over 50 documents attached as files to the COA application that spelled out as much about the plans as possible. This included mission and lost-link plans; emergency plans; graphics and latitude/longitude descriptions of the COA application area; the zones; the routes; the keep-out zones; and the NASA DFRC management processes for reviewing and approving missions for flight. It was clear that the FAA had considered the 2006 WSFM plan to be very complex. The Ikhana project team decided to submit the 2007 WSFM COA application as early as possible with a target of providing the FAA with six months for review though the FAA typically requires 60 days to review a "vanilla" COA application.

B. Application for the Certificate of Waiver or Authorization

The 2007 WSFM COA application was submitted online. The UAS COA Online System provided a framework for the required information.

1. Preparation and Submission

The Ikhana project personnel began preparing the formal COA application and entering that information into the FAA UAS COA Online System in mid-January of 2007. Although mission plans were mature, it took until mid-February to put these plans into forms suitable for submission, and to cover the variety of topics that were required by the new UAS COA Online System that had not been previously considered. The application was submitted to the FAA on February 27, 2007. The preparation of the COA application was a lengthy (two-month) process, but the time spent in preparing a complete and thorough application package was worthwhile from the project point of view. Once the COA application was submitted, very few complications and issues were experienced by the Ikhana project during the FAA review process. The UAS COA Online System itself helped to focus and streamline the approval process. A face-to-face meeting with staff of the FAA Headquarters UAS Program Office and the affected air route traffic control centers (ARTCCs) was invaluable in solving several problems with the proposed missions and ensuring a common FAA Headquarters, ARTCC, and NASA DFRC understanding of the missions.

2. The Online Application System for the Certificate of Waiver or Authorization

One of the weaknesses in the original UAS COA application process was the application process itself: there was no single location at which the entire application resided after it was sent to the FAA. To complicate matters, when the FAA asked for and received clarification on specific areas, there was no guarantee that the initial application would be amended with the new information. This problem and others were solved with the UAS COA Online System. In November 2006, the UAS COA Online System was unveiled and used for subsequent COA processing. The UAS COA Online System was based on an existing tool the FAA was using to document and evaluate new potential obstructions in the vicinity of airports (such as new buildings or radio towers). The UAS COA Online System provides the applicant with a structured framework within which to answer questions and provide attachments with additional information. A side benefit of the UAS COA Online System is that it also allows the FAA to use electronic methods to evaluate and track the evaluation of COA applications within the FAA. The UAS COA Online System breaks up the application into a series of World Wide Web pages to address specific information and allow the applicant to attach files that further explain a particular subject. Some of the areas

addressed included: an overview or general description, a description of the aircraft and its capabilities, aircraft modifications, aircraft airworthiness, pilot qualifications, aircraft avionics, electronic and visual surveillance capability, and air traffic control (ATC) communication capabilities.

C. The Western States Fire Missions Plan

The 2007 WSFM required a total of four to five flights of 12 to 24 hr in duration. The FAA requirement to submit flight plans three business days prior to the planned flight drove a requirement to submit flight plans on Monday for Thursday missions. Friday and Saturday were considered backup mission days. Back-to-back missions would not be attempted due to crew rest and aircraft maintenance requirements. Wildfire emergencies, especially in the southern California area (as demonstrated in 2006) could drive the number of flight requests above that previously mentioned. The Ikhana project team would communicate these changes to the FAA as quickly as possible.

D. Altitude

Originally the 2007 WSFM was planned to be flown within Class A (positively controlled) airspace and above Reduced Vertical Separation Minimum (RVSM) airspace (41,000 feet, or FL410). The plan was changed to fly below RVSM airspace (18,000 to 29,000 feet, or FL180 to FL290) due to aircraft performance considerations. All flights were to be conducted in Class A airspace, within which ATC provides aircraft separation, thus overcoming the UAS aircraft's "see and avoid" limitation. Real-time changes in altitude would be performed as requested by ATC at any time during the mission. Climbs and descents between the runway and Class A airspace were to take place completely within the R-2515/R-2508 Special Use Airspace (SUA).

E. Certificate of Waiver or Authorization Application Geographic Boundaries and Zone Definition

The following discussion of the operating area identified in the COA application will be referred to as the "COA application area" since the COA that was eventually approved authorized operations in only a portion of this area. The outer boundary of the COA application area was selected to satisfy the needs of the Wildfire Research and Applications Partnership. The COA application area encompassed all of the forested area of the western United States subject to wildfires of interest to the NIFC and local firefighters. Two regions of the western United States warrant further discussion. The first consists of the western areas of Oregon and Washington state. This region was not included in the COA application area because it does not have a significant history of wildfire. The second region includes locations in Nevada and Utah that have no significant history of wildfires, but were included in the COA application area because they were needed to efficiently access wildfire-prone areas in Idaho, Montana, and Wyoming.

The overall COA area was divided into three areas, designated as Zone A, Zone B, and Zone C (see Fig. 2). This was done for several reasons. Despite its long endurance, the Ikhana aircraft does not have the range to visit wildfires that are in highly separate geographic locations. In other words, the aircraft does not realistically have the range and endurance capability to visit, for example, wildfires located in areas as widely separated from each other as Arizona and Washington state. Another reason for creating multiple zones is that the requested application area covered all or parts of six FAA ARTCCs. The complexity of FAA coordination with multiple ARTCCs increases as the number of ARTCCs increases. In an effort to reduce the complexity of coordination within the FAA, the NASA DFRC made a decision to limit the size of each zone to include all or parts of a maximum of three ARTCCs. Because the location of the NASA DFRC is within the Los Angeles Center (LA Center) ARTCC, LA Center is included in all three zones. Coincidentally, these zone boundaries match well with the range capability of the Ikhana aircraft.

F. Range Safety Keep-out Zones

A standard provision of UAS COAs approved by the FAA restricts unmanned aircraft from flying over densely populated areas. Additionally, it is a standard requirement for the NASA DFRC Range Safety Office (RSO) to analyze UAS flights for risk to the public. The RSO created specific keep-out zones within the COA application area to identify those areas where high population densities would necessitate additional protection for the public. These keep-out zones were classified as either densely populated or medium-density populated areas. The higher density populated areas were designated as "red" zones that the aircraft had to avoid in all cases. The areas with medium-density population were designated as "yellow" zones that the aircraft could fly over if the pilot were in real-time control of the aircraft, and if the aircraft was in good health. Figure 4 shows the NASA DFRC RSO population density keep-out zones. The NASA DFRC made the determination that if, due to a lost communications uplink, the pilot did not have real-time control of the aircraft it could not fly over even the yellow keep-out zones. Accordingly,

the aircraft would be pre-programmed with a lost-link program that did not overfly the yellow keep-out zones. The red keep-out zones encompass the large metropolitan areas in the west, such as Los Angeles, San Francisco, and Denver, but are detailed enough to give flexibility to fly over forested areas that are close to those metropolitan areas. The definition of the red and yellow keep-out zones is controlled by the NASA DFRC RSO, hence the RSO can make real-time decisions to allow the aircraft to be flown into an area previously identified as keep-out zone. This allows increased flexibility for flying over populated areas that have been evacuated due to a wildfire, for example, or for flying over areas that would normally serve as a buffer around highly populated regions. The RSO primarily used the 2000 United States Census to define the keep-out zones, but also used other sources of information to better depict the actual population densities in 2007. All of the keep-out zones were displayed to the pilot in real time for situational awareness.

G. Flight Routes within Zones

A route was identified in each of the flight zones, and the routes were named Route A, Route B, and Route C. The original idea behind defining routes for each of the zones was to provide a "backbone" or "highway" that would be used for the aircraft to fly along, and then to "spoke" out to a particular wildfire area of interest. This is not very efficient, but the assumption was that the FAA would be willing to accept this methodology more readily than a "fly directly from fire to fire" approach. The routes were defined to satisfy several requirements: first, to avoid all RSO keep-out zones; second, to maximize coverage of forested areas that would be expected to burn (to potentially discover "new" wildfires); and third, as much as reasonable, to avoid adverse winds, turbulence and weather that might form on the east slopes of mountains. One reason for weather avoidance was that these routes were intended to be the basis of the mission's lost-link program. If the aircraft were autonomously returning to Edwards Air Force Base (EAFB) without a communications link to the ground, the NASA DFRC would want the aircraft to avoid areas where extreme weather often forms. The FAA eventually rejected the "spoke" approach in favor of the "fly directly from fire to fire" approach, because the latter approach more closely resembles the behavior of other aircraft flying in the NAS. Figure 3 shows each of the three "backbone" routes within its respective zone.

H. Emergency Planning

Emergency planning occupied the most time during the project, and a significant amount of project personnel resources were dedicated to addressing this problem over an approximately six-month period. A COA Special Provision that "Emergency diversion sites shall be identified for each specific mission/route" and the additional NASA DFRC management requirement that the controlling authority of any primary emergency landing site (ELS) be fully briefed on the risks and procedures of the aircraft were the two driving requirements for this effort. Two aircraft emergency scenarios were specifically addressed when defining emergency landing sites: loss of the aircraft's onboard generator, and loss of the engine.

During the mission-planning phase for a manned aircraft, the pilot may identify (or predesignate) a small number of airfields that could be utilized in the event of an emergency. During an emergency, the pilot would determine if the aircraft could make it to one of those predesignated airfields, and if not, would look out the windows of the aircraft and select a suitable landing site based on the options presented below. This same process applies to a UAS flight, except that if the aircraft could not make it to a predesignated airfield, the limited field of view provided by the aircraft's cameras restricts the pilot's ability to select a suitable landing site. Thus, the FAA directed that both primary and secondary emergency landing sites be preselected during mission planning.

1. Generator Failure

In the event of electrical or generator failure, the aircraft is flyable but is operating on backup battery power. Three predesignated ELSs for this scenario were defined as primary ELSs and included Edwards Air Force Base (AFB), Michael Army Airfield at Dugway Proving Ground, Utah, and Mountain Home AFB, Idaho. The Ikhana aircraft has sufficient battery backup power to fly for more than three hours and can travel at least 400 nautical miles (nm) in that time. Figure 5 shows how the three ELSs fully cover the COA application area. Although it was relatively easy to identify the desirable locations of these three sites, getting final approval to use them took a great deal of time. The NASA DFRC management requirement to ensure that primary ELS personnel were fully briefed concerning risks and procedures drove the need to develop and negotiate individual Emergency Landing Operations Plan agreements with Dugway and Mountain Home AFB. The agreements detailed the conditions of a landing attempt, the risks of attempting to land, the flight profile(s) to approach the site, areas to avoid near or at those sites, ditch location(s), aircraft handling procedures, and personnel contact procedures and timelines. It took over four months of work to generate, negotiate and finalize those two agreements.

2. Loss of Thrust (Engine)

In the event of a complete loss of thrust, in which the automatic engine restart capability is unsuccessful, the aircraft becomes a glider and an emergency landing location is required. These predesignated ELSs were named secondary ELSs and eventually included over 280 sites. A COA Special Provision included the requirement to remain within 100 nm of a secondary ELS. The Ikhana project calculations showed that a 50 nm radius was more appropriate and sufficiently conservative for these flights. The COA requirement drove the need to "wallpaper" the COA application area with predesignated secondary ELSs. Although the aircraft will also be using backup battery power, the aircraft will glide to the ground before the battery power is exhausted. A five-member project team devoted more than two months to identifying potential sites, reviewing those sites with the NASA DFRC RSO, and gathering additional information on the acceptable sites. The information about each site was entered into a database for tracking and configuration management purposes. The information gathered about each site included location (latitude, longitude, and fix-radial-distance), altitude, length, local sheriff contact information, where to obtain weather information, potential hazards in the area, and images of the site from several viewpoints (overhead, approach, et cetera). Additionally, the pilots categorized each site by desirability (1 = a good landing site, 2 = an OK landing site, 3 = a not-so-good landing site, 4 = a crash landing site). This process continued into the preflight planning process with team members analyzing each submitted flight plan to identify the preferred secondary ELSs for each portion of the flight plan and making that information available in book form to GCS personnel prior to takeoff. The entire big book of all sites was also available in the GCS for those times when the aircraft had to deviate from the filed flight plan for various reasons. Figure 6 shows a snapshot of the secondary ELS database and the site coverage over the COA application area.

I. Emergency Landing Site Limitations

Several limitations were placed on what sites could be designated as a secondary ELS. To maximize the probability of landing the aircraft, a runway of at least 4000 ft, and preferably 5000 ft, is necessary. Although a runway is preferable, any sufficiently long, flat strip of ground would be acceptable.

The ELS landing site should:

1. Be outside of the NASA DFRC RSO keep-out zones
2. Provide approach (go-around) flight paths outside of the NASA DFRC RSO keep-out zones
3. Provide a minimum of 4,000 ft (5,000 ft desirable) of paved runway (this is a guideline only)
4. Be within COA boundaries (some flexibility is available in the event of an emergency)
5. Not be an FAA active public or joint-use airfield
6. Not be a military airfield unless appropriate personnel have been briefed on the risks involved
7. Be flat terrain without obstacles, such as
    a. Open fields
    b. Meadows
    c. Dry lakebeds
    d. Farm fields
    e. Salt flats, or
    f. Similar locations.

Small airfields might appear to be suitable emergency landing sites, since those sites could be equipped and have trained personnel for an aircraft emergency crash scenario; however, Ikhana does not have the ability to "sense and avoid" other aircraft in the airfield landing pattern, or in the vicinity of the airfield. Since the Ikhana aircraft does not have sufficient "see and avoid" capability, the FAA restricted the UAS from attempting to land at those locations. Many of the secondary ELSs turned out to be abandoned airfields and lakebeds.

V. Approved Certificate of Waiver or Authorization

The COA that was approved by the FAA was not identical to the application. The most notable change from the application was the limitation of the COA operating boundary to 75 nm from the predescribed "backbone" routes. This meant that the aircraft would not be able to image any wildfire sites beyond the 75 nm limit. Unfortunately, these routes had not been selected (or analyzed) to go over high-likelihood wildfire locations. Other restrictions of the approved COA included requirements for coordinating with affected ARTCCs three business days in advance, avoiding areas where convective significant meteorological information warnings (SIGMETs) have been issued, and avoiding areas affected by announced global positioning system (GPS) testing and areas affected by receiver

autonomous integrity monitoring (RAIM) -predicted outages. Each of these restrictions each came into play in some way during the execution of the WSFM.

VI. 2007 Mission Operations

The first 2007 WSFM flight was flown on August 16, 2007 and the eighth and last flight was flown on October 28, 2007. The primary science objectives of WSFM #1 through WSFM #4 were to the demonstrate the NASA Ames IR sensor and to supply imagery of wildfires within 10 minutes to wildfire Incident Commanders (ICs) on the ground. Western States Fire Missions #5 through #8 were flown in response to requests from various government agencies during the California wildfire disaster to provide the IR image capture and distribution capabilities recently demonstrated. Although the last four flights were very similar to one another, each of the eight flights was unique and provided different challenges.

A. WSFM #1 – August 16, 2007

This initial flight was intended to be a relatively short flight of approximately 10 hr in duration that stayed almost entirely within the California border. The flight duration was 9.5 hr and imaged the Zaca, Tar, Colby, and Yosemite wildfire locations. That image data was transferred down to the ground within approximately 10 minutes after acquisition. During an unexpectedly short pre-mission teleconference, the mission route plans were accepted by the FAA and the affected ARTCCs. The limits of the COA operating boundary were tested immediately. The three-day-prior flight plan submission to the FAA included one wildfire that was at the limit of the 75 nm range from the Route A backbone. The FAA granted permission to fly just beyond the COA boundary to reach this wildfire. Based on the approved route, a subset of mission-specific secondary ELSs were selected, reducing the 280+ predesignated secondary ELSs to approximately twelve. While every effort was made to file the flight plan 24 hr in advance in accordance with a Special Provision of our COA, technology limited the team to actually filing the plan within 22 hr of the proposed flight (there is no date field, and flight plans are dropped if they are not activated within two hours after the intended departure time). This prompted the agreement that the flight plan would be submitted to the FAA and ARTCCs in the same manner as the three-day-prior route had been submitted (by electronic mail) 24 hr in advance and then actually be filed (put into the system) as appropriate. In general, the flight plans were filed with Edwards AFB Base Operations. During this mission it appeared that local ATCs had, for the most part, been briefed in advance and were expecting the aircraft. Figure 7 shows a WSFM #1 data image of the Zaca wildfire indicating the previously-known fire perimeter in aqua, the current fire perimeter in the darker blue, and fire detects in yellow. The image, georectified and draped over Google Earth®, was delivered to the IC in near-real-time and provided information with which to strategize and initiate action plans.

B. WSFM #2 – August 30, 2007

This flight was a medium duration flight that visited wildfire locations in Idaho, Montana, and Wyoming. The flight duration was 16.1 hr and imaged at least five wildfire locations. Imaging wildfires north of the approved COA boundary in Idaho and Montana was of high interest to the researchers and firefighters, so a request for an extension of the COA boundaries was submitted to the FAA. The initial route that was submitted included points in Montana utilizing the extended COA boundaries. Unfortunately, the COA boundary extension request was not approved. Multiple large wildfires were burning within the approved COA boundaries in Idaho, Montana, and Wyoming, so a second three-day-prior submission was made using the original COA boundary. This submission resulted in Salt Lake Center requesting several points be moved. An ATC assigned airspace (ATCAA) had recently been created which the aircraft needed to avoid. Salt Lake Center suggested an alternative, but their suggested route went directly over an RSO population keep-out zone. After receiving the coordinates of the new ATCAA, the route was moved to avoid both the ATCAA and the RSO population keep-out zone. Now with an FAA-approved route, GPS testing became an issue because a Notice to Airmen (NOTAM) had been released identifying a GPS testing area that impacted the route. Because of the large geographic region covered by these flights, GPS testing activities at Naval Air Warfare Center (NAWC) China Lake, Nellis AFB, and the Utah Test and Training Range (UTTR) often impacted the missions. This particular mission was subsequently postponed 24 hr to coordinate Ikhana's flight with those GPS testing activities. On the morning of the flight the Edwards AFB runway was closed for repair, resulting in an additional postponement. A week later, having again coordinated for GPS testing, the mission was flown. This flight tested real-time weather re-routing. On the way to Idaho, a large SIGMET was issued across the planned route. Ikhana requested a weather deviation and ATC directed a significant flight path deviation around the thunderstorm activity that allowed the mission to continue to the wildfires. The return route was back on the preplanned and filed route. Figure 8 shows a WSFM #2 overhead view of the Castle Rock wildfire as it threatened

the towns of Ketchum and Sun Valley in Idaho. Burned areas are in yellow while new fire detects are in red. Figure 9 shows a WSFM #2 three-dimensional (3D) view of the Castle Rock wildfire showing the red fire detects on a mountainside, threatening the valley below.

C. WSFM #3 – September 7, 2007

This flight was a long duration mission that visited wildfire locations in California, Oregon, and northern Washington state. The flight duration was 20 hr and the aircraft imaged a total of 11 wildfires. The total distance covered was approximately 3200 nm. The three-day-prior notification resulted in a negotiation of the route of flight within the area controlled by Seattle Center. The concern was proximity to airspace that was used heavily during the day. After considering several alternative routing options, as well as the time of day Ikhana was expected to be traversing the area in question and the assurance that Ikhana could be re-routed in real time, the route was approved as submitted. Global positioning system testing was again an issue and not only was takeoff time delayed until the conclusion of the GPS testing, but the timing over the wildfires to be imaged was impacted. The one-day-prior route submission to the FAA and ARTCCs reversed the route's direction of flight so that the sun angles during the imaging of the wildfires and the burn areas would be more favorable. The flexibility of ATC was again demonstrated when ATC allowed a real-time movement of one of the wildfire incident loiter locations. This was necessary because the wildfire had moved significantly since the original flight plan had been submitted three days prior to the flight. Figure 10 shows a 3D view of the "hot detects" of the WSFM #3 Moonlight wildfire in northern California. Because the imagery is laid over Google Earth®, it can be rotated and displayed as a 3D image. Fire Camp personnel appreciated their ability to "see" wildfire areas for which they had lacked "intelligence."

D. WSFM #4 – September 27, 2007

This flight was a relatively short duration flight of 9.9 hr. The flight was focused on obtaining BAER post-burn imaging data of four locations inside California. The mission covered approximately 1800 nm. Because Ikhana was essentially returning to previously-imaged wildfires and the third mission planned within Zone A, the three-day-prior submission was approved with little discussion. The ARTCCs involved seemed familiar with Ikhana's capabilities and its responsiveness to their requests.

E. WSFM #5 – October 24, 2007

This was the first of four flights that focused on southern California wildfires. The area of interest was south of the approved COA boundary, so the FAA used a process to quickly amend the existing WSFM COA to authorize the aircraft to fly into that area. In this particular instance, the southern COA boundary was extended to within 10 nm of the United States and Mexico border, and the three-day-submission requirement was reduced to two days, and later to 24 hr, prior to the proposed mission. There was a Nellis AFB GPS testing NOTAM issued that would have conflicted with the flight, but by consulting with Nellis AFB personnel and explaining the southern California wildfire emergency situation, the WSFM flight team was able to obtain permission to proceed. The Ikhana project notified the FAA of the coordination effort with Nellis AFB activities. This first flight of the emergency response missions was 9.0 hr in duration and visited 10 wildfire locations in the Los Angeles and San Diego areas. Air traffic control allowed significant real-time mission re-planning that allowed the imaging plan to adapt to current wildfire conditions. An example of the real-time re-planning was the ATC authorization to fly over wildfires within the boundaries of United States Marine Corps Base Camp Pendleton.

F. WSFM #6 – October 25, 2007

This was the second of four flights focused on the southern California wildfires. The flight duration was 7.8 hr and the flight visited seven wildfire locations in the Los Angeles and San Diego areas. Figure 11 shows a WSFM #6 "hot detects" image of the Ammo wildfire within the boundaries of United States Marine Corps Base Camp Pendleton.

G. WSFM #7 – October 26, 2007

This was the third of four flights focused on southern California wildfires. The flight duration was 8.7 hr and the flight visited eight wildfire locations in the Los Angeles and San Diego areas, including the Santiago wildfire. During the early morning preflight briefing the decision was made to reverse the planned route, due to weather. Edwards AFB personnel were not yet on duty to accept this flight plan revision, giving the Ikhana team their first opportunity to file a flight plan directly with a Flight Service Station (FSS). The team encountered two challenges. The first was beginning a flight plan by exiting a restricted area and ending a flight plan by entering a restricted area.

The FSS resolved this using the "remarks" section of the flight plan form. The second challenge was explaining to the FSS that Ikhana is an MQ-9 unmanned aircraft requiring "0" souls on board. Because of the ongoing evacuations in the areas affected by the wildfires, the NASA DFRC RSO removed a previously existing population keep-out zone; this allowed expanded imaging of the Poomacha wildfire area. Figure 12 shows a WSFM #7 3D image of the Santiago wildfire "hot detects" in southern California.

H. WSFM #8 – October 28, 2007

This was the fourth of four flights focused on the southern California wildfires. The flight duration was 7.1 hr and the flight visited eight wildfire locations including some to obtain BAER post-burn imagery. Figure 13 shows an additional BAER post-burn imagery opportunity that was gathered from the 2006 Esperanza wildfire location.

VII. Noteworthy Topics Related to Performing the NASA 2007 Western States Fire Missions

A. Working with the FAA Headquarters Unmanned Aircraft Systems Program Office

The FAA Headquarters UAS Program Office support for flying UAS in the NAS has been outstanding. The Program Office was created while 2007 WSFM preparations were underway. The leadership the Program Office has provided to the UAS community has been clear and useful and has continued to move the community closer to the goal of "file-and-fly." The introduction of the UAS COA Online System process has clarified and streamlined the process of applying for a UAS COA. The support and the commitment of the Program Office to make the 2007 WSFM successful was consistent and significant. The WSFM COA has been described as the "mother of all COAs" in scope and complexity; the FAA Program Office support is exactly what made these missions possible.

B. Working with the FAA ARTCCs – General

The NASA DFRC team spent a significant amount of time communicating and conferring with the affected FAA ARTCCs while the FAA was evaluating the COA application. This culminated in a three-day face-to-face meeting during which all aspects of the planned operation were discussed. The communication and understanding that were reached were invaluable. The FAA ARTCCs that were affected by this COA were Los Angeles, Oakland, Seattle, Salt Lake City, Denver, and Albuquerque. Pre-mission, each of the ARTCCs demonstrated a commitment to solving the challenge of flying a UAS in their airspace. During the missions, the cooperation of ATC with the changing flight plan desires of our customer was flawless. Even after multiple requests for changes to the flight plan in the congested airspace around Los Angeles, ATC continued to approve the requests almost without hesitation. Several times, ATC queried the Ikhana pilots and were surprised to hear that the pilots were not in the aircraft, and the aircraft was being flown remotely. Post-mission debriefings with the ARTCCs highlighted that the degree of communication and cooperation between the NASA DFRC team and the ARTCCs was sufficient to safely and successfully accomplish the missions.

C. Pre-mission Coordination with the FAA ARTCCs and Flight Plan Submission

The mission planning process began with the NASA Ames team members deciding which wildfires were of interest and within 75 nm of a particular route. This was communicated to the NASA DFRC and a flight plan was prepared. The flight plan submitted to the FAA defined a flight path that included as many of those wildfires as possible and avoided overflight of the Range Safety keep-out zones. The flight path was created as a series of latitude and longitude points that were also converted into a fix-radial-distance (FRD) waypoint format (that the FAA prefers to use). Holding areas were defined as 15 nm circles centered on the wildfires to be visited. Three COA Special Provisions determined how that flight plan was communicated to the FAA:

1. Operations shall be coordinated with the impacted ATC facilities three business days in advance. Specific routes shall be defined at this time.
2. NASA shall file an instrument flight rules (IFR) flight plan 24 hr in advance of the requested flight.
3. NASA shall initiate a mission planning teleconference with all impacted FAA facilities 24 hr prior to the proposed departure time.

The flight plan was mailed electronically to the FAA Headquarters UAS Program Office and to the ARTCC representatives at least three days prior to the planned flight. This usually entailed flight planning on Sunday, and submitting the flight plan on Monday morning for a Thursday morning takeoff time. On Wednesday (the day prior to the flight), the flight plan electronic mail was resent with little or no changes, an IFR flight plan was filed, and a meeting was held between the NASA DFRC, NASA Ames, the FAA Headquarters UAS Program Office, and the

ARTCCs. At this meeting the flight plan and the objectives for the flight were reviewed. The value of this pre-coordination became apparent during a flight as ATC prompted the pilot with the correct next waypoint in the flight plan. For WSFM #5 through WSFM #8, which were flown on October 24th, 25th, 26th, and 28th, the three-day-prior notice was not given to the FAA. In these cases, the flight planning for the next day was occurring while the aircraft was being flown, and was electronically mailed soon after the aircraft landed. This worked because only one ARTCC was affected (LA Center). Los Angeles Center regularly works with Ikhana-type aircraft, and LA Center operations were directly affected by the southern California wildfire emergency. The wildfires were so widespread in the LA Center operational area that airports were being closed to accommodate firefighting operations and ATC communications transmitters/receivers were being threatened and consumed by the wildfires.

D. Global Positioning System Testing

Because the Ikhana is unmanned and depends on GPS and inertial navigation, the FAA issued the following COA Special Provision: "NASA shall not allow a mission to pass through an area affected by planned GPS testing,…" If the GCS were to lose the command link with the aircraft, the aircraft would then be using its internal GPS and inertial navigation system to fly along the lost-link programmed mission to return to Edwards AFB airspace. Although this Special Provision did not seem to be a problem initially, the NASA DFRC and Edwards AFB are geographically near both NAWC at China Lake, California, and Nellis Air Force Base, Nevada and their associated Special Use airspace and test ranges. Nellis AFB is noteworthy in that it hosts the U.S. Air Force Red Flag exercises at least three times per year for approximately two weeks at a time. Red Flag exercises include GPS testing. China Lake operations also regularly involve GPS testing. The GPS testing events are announced to the aviation community by way of the FAA NOTAM system. During the pre-mission planning for several missions, it became necessary to coordinate directly with Nellis and China Lake personnel to attempt to deconflict Ikhana flight plans and GPS testing operations at those sites. In most cases the GPS testing had higher priority, but in the case of the last four missions that imaged the southern California wildfires, Nellis AFB personnel determined that the wildfire emergency situation in southern California elevated our missions to a higher priority than that of their GPS testing operations.

E. Line-of-Sight Command and Control Frequency Availability

The Ikhana project has limited access to the aircraft line-of-sight (LOS) command and control frequencies. Because there are higher priority users in the NASA DFRC and Edwards AFB area that use those frequencies, the Ikhana flights are generally planned on a non-interference basis. The southern California wildfire emergency declaration increased the priority of WSFM flights #5 through #8 so that a set of the LOS command and control frequencies was made available all day every day.

VIII. Conclusion

The National Aeronautics and Space Administration (NASA) 2007 Western States Fire Missions flights successfully demonstrated the ability of a large unmanned aerial system to fly in the national airspace system using the current NASA Dryden Flight Research Center (DFRC) and Federal Aviation Administration (FAA) safety guidelines and approval processes. The flights also demonstrated the ability to deliver useful near-real-time information to firefighters on the ground. The later missions demonstrated an ability to fly in the national airspace system with fewer than 72 hours notice to the FAA, but this was in response to an emergency situation that will not pertain to all future operations. The NASA DFRC resources required for pre-mission planning and coordination were significant and will need to be reduced to approach the goal of "file-and-fly" for large unmanned aerial systems in the national airspace system.

Acknowledgments

The authors thank the Federal Aviation Administration and the FAA Headquarters Unmanned Aircraft Systems Program Office for that agency's efforts, commitment, and hard work toward making file-and-fly for unmanned aircraft in the national airspace system a reality.

Figures

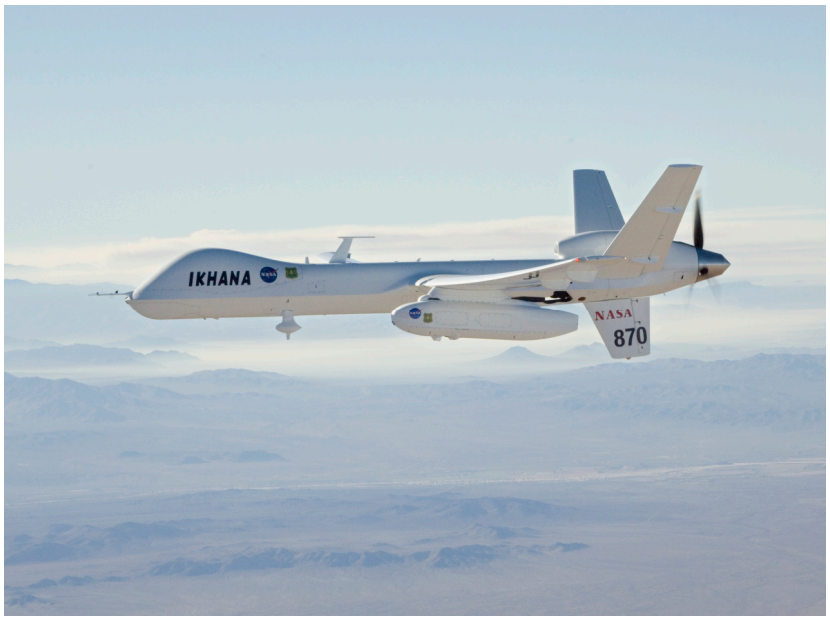

Figure 1. Ikhana flying a Western States Fire Mission.

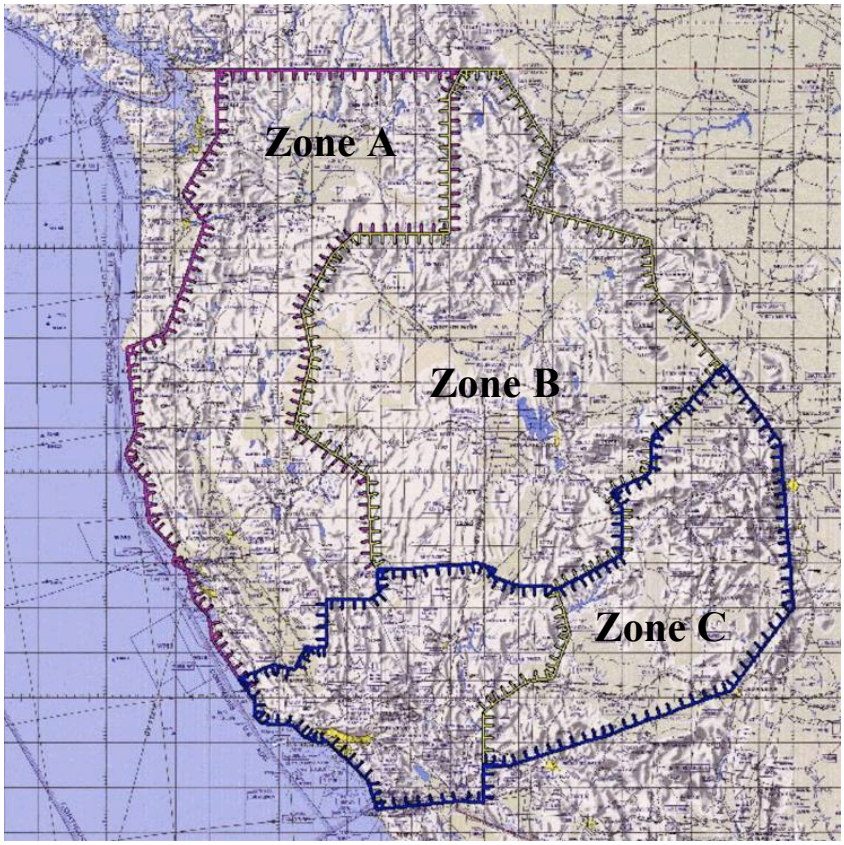

Figure 2. Area for which the certificate of waiver or authorization was applied.

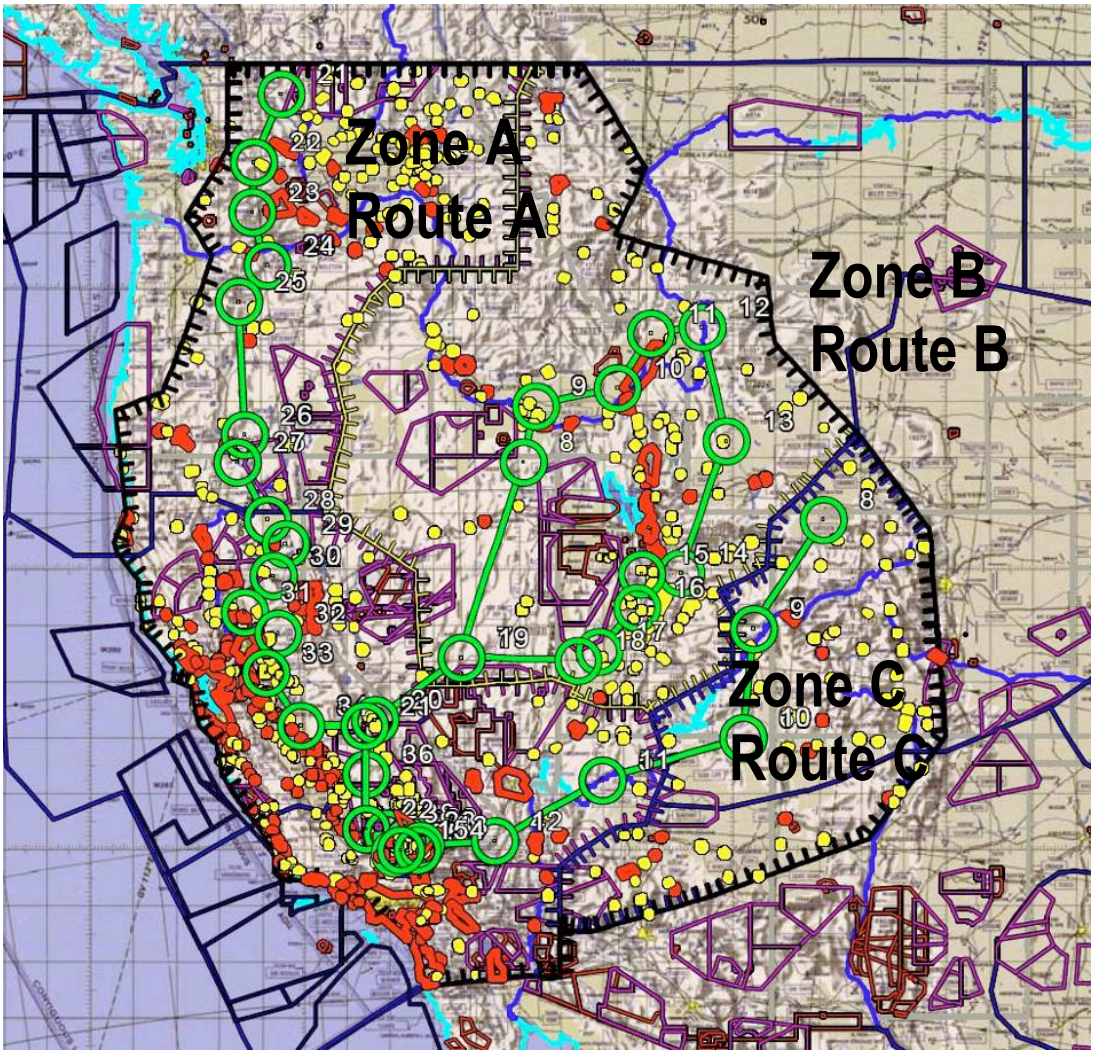

Figure 3. Routes described in the certificate of waiver or authorization application.

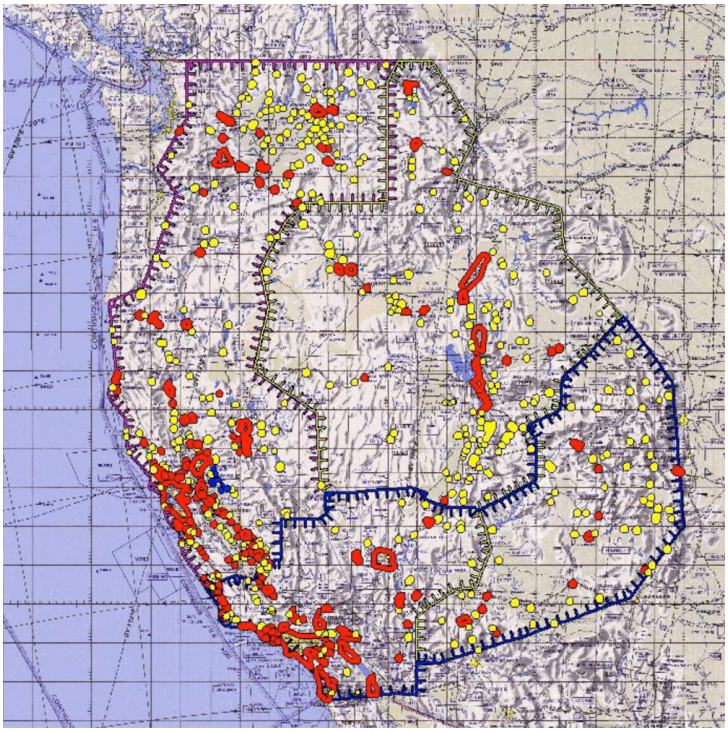

Figure 4. Population density keep-out zones.

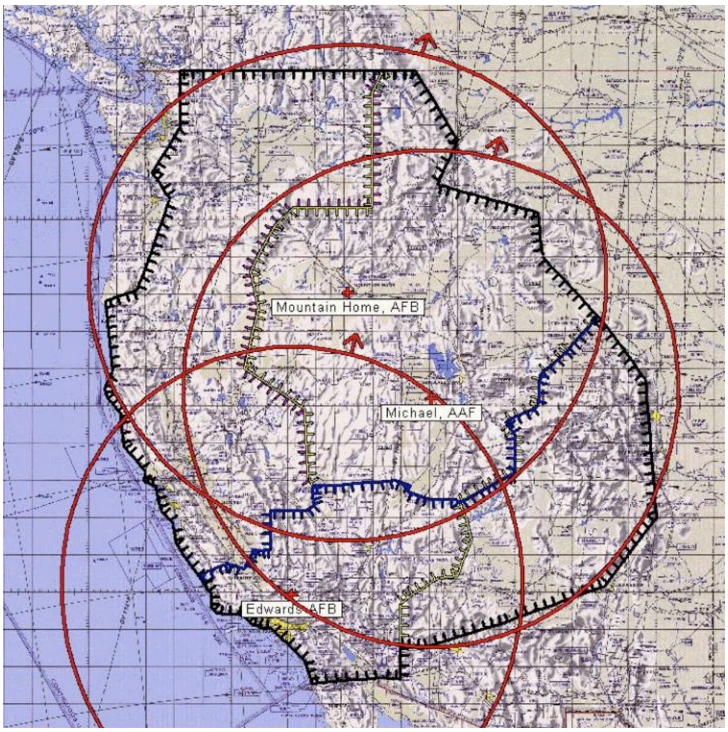

Figure 5. Primary emergency landing sites.

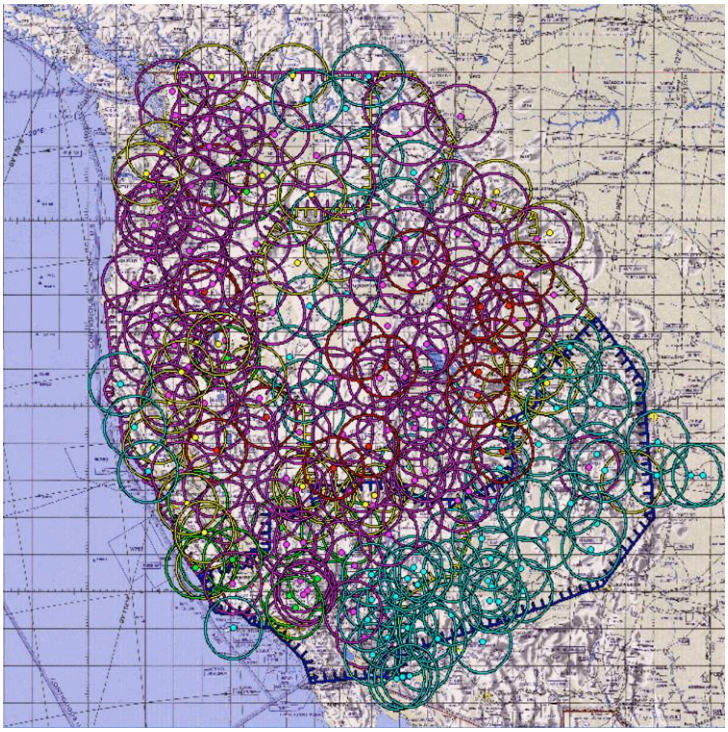

Figure 6. Secondary emergency landing sites.

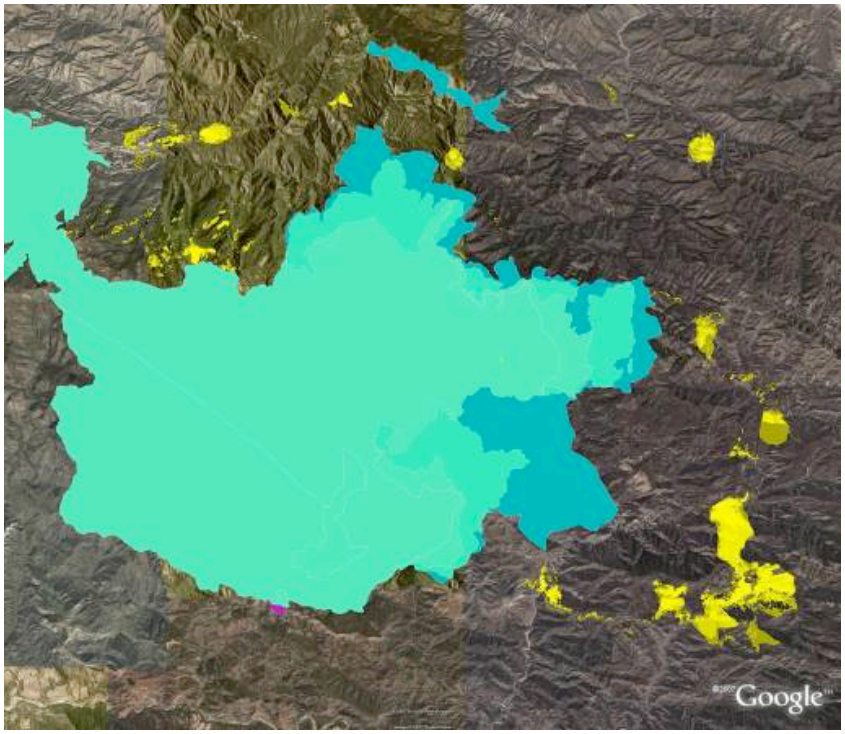

Figure 7. WSFM #1 data image of the Zaca wildfire.

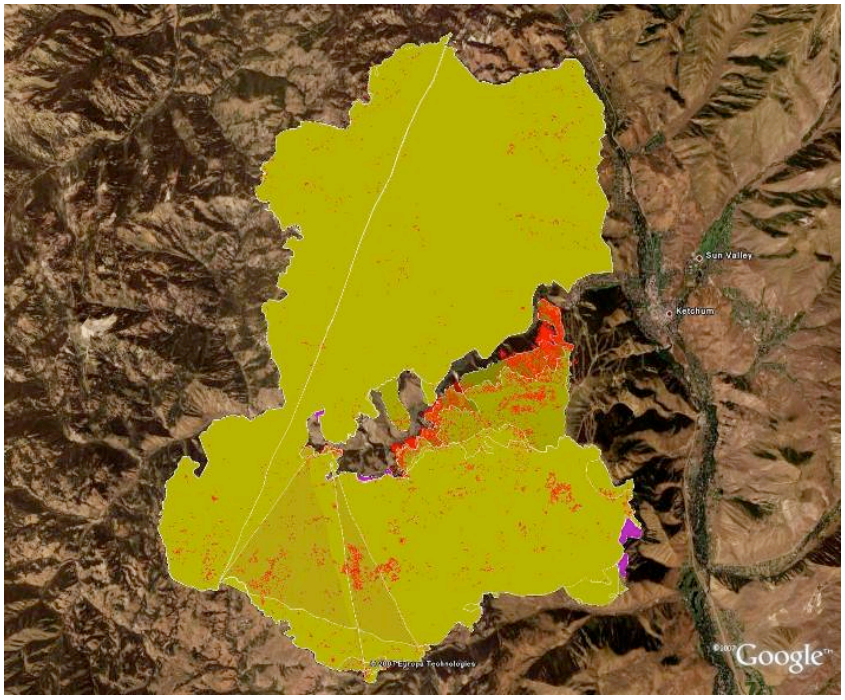

Figure 8. WSFM #2 overhead view of the Castle Rock wildfire.

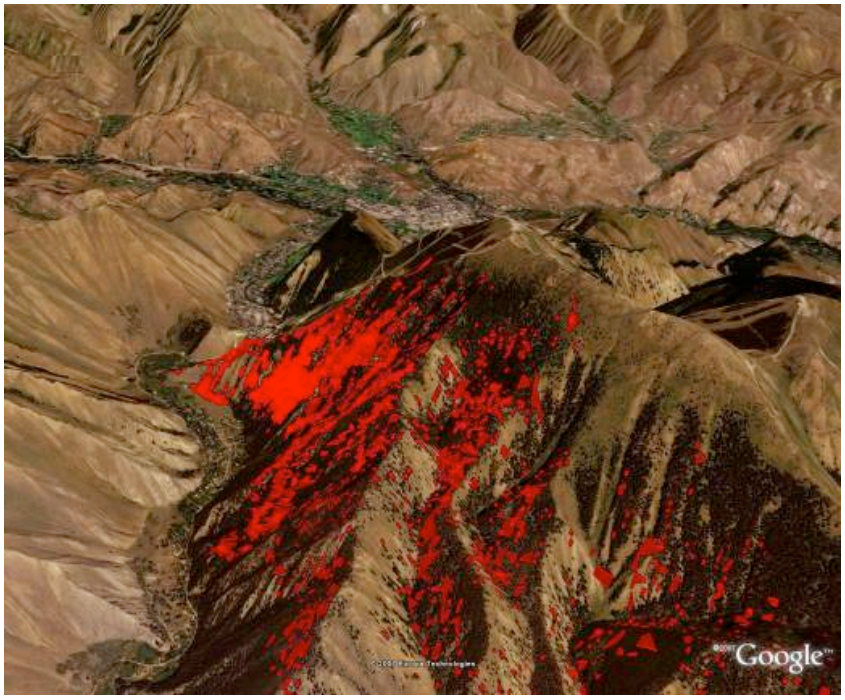

Figure 9. WSFM #2 three-dimensional view of the Castle Rock wildfire.

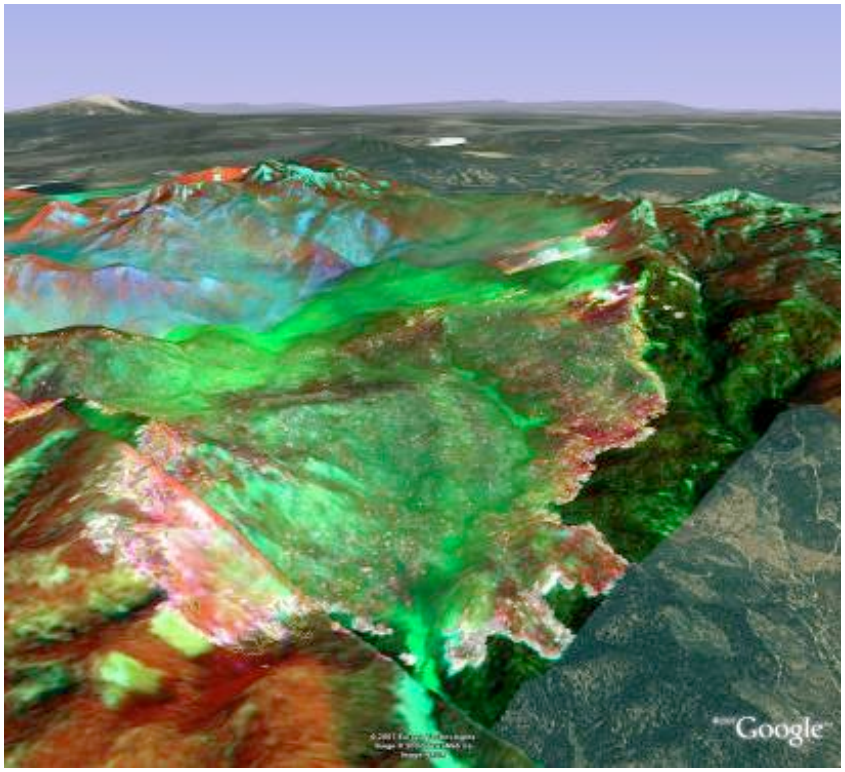

Figure 10. WSFM #3; three-dimensional "hot detects" view of the Moonlight wildfire.

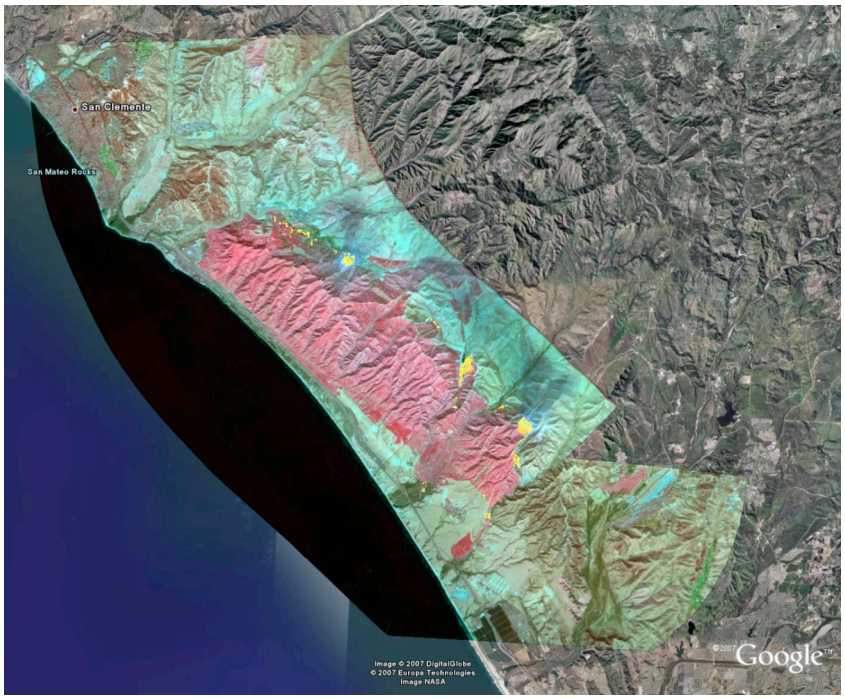

Figure 11. WSFM #6 "hot detects" view of the Ammo wildfire.

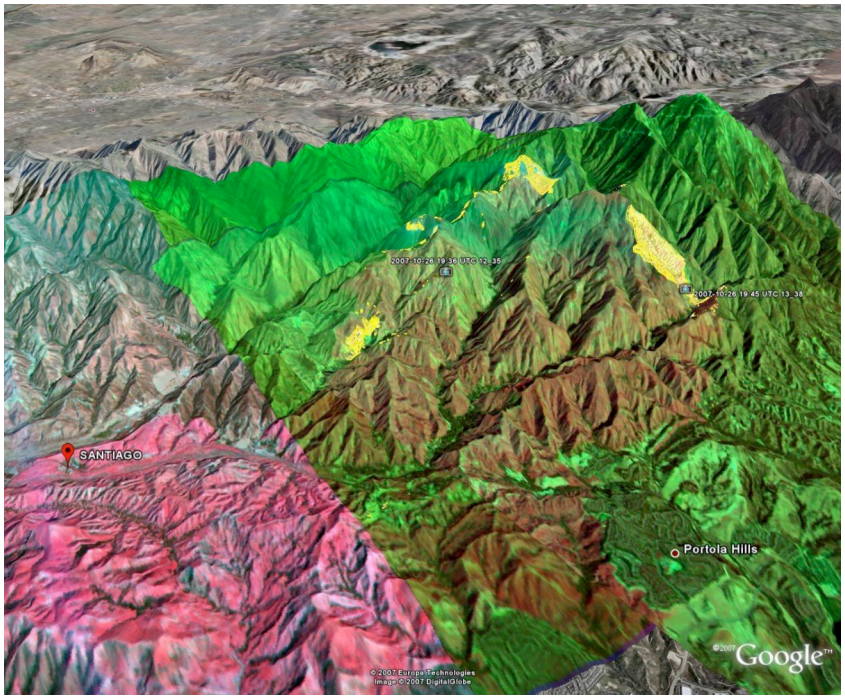

Figure 12. WSFM #7 three-dimensional "hot detects" view of the Santiago wildfire.

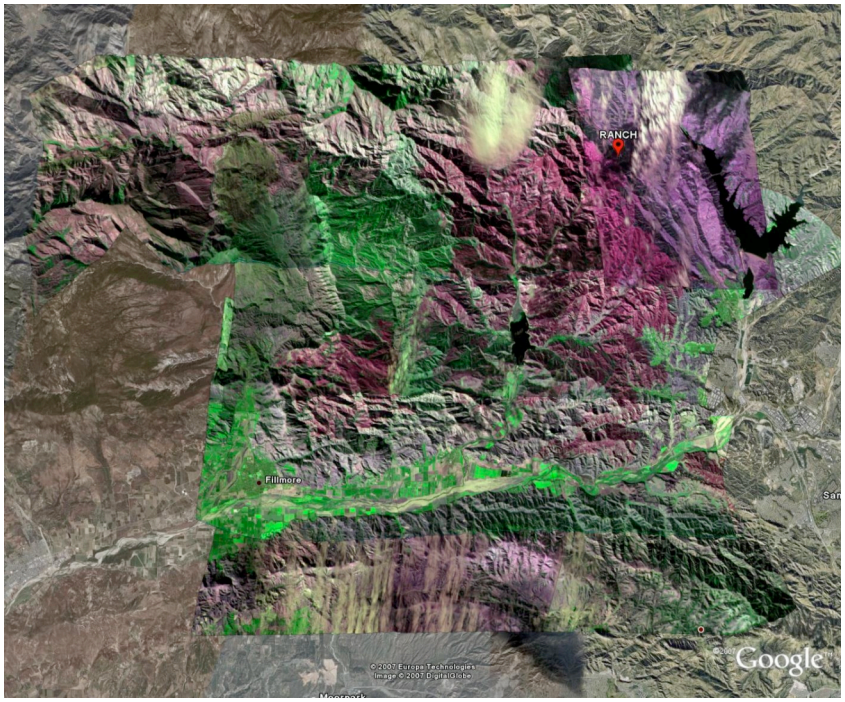

Figure 13. WSFM #8 BAER post-burn imagery of the 2006 Esperanza wildfire.